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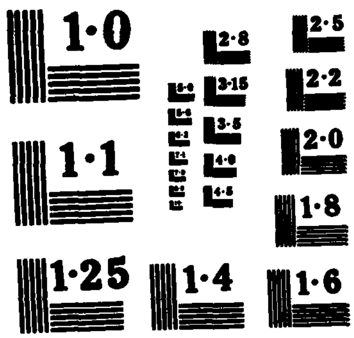

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An Evaluation of the Ocean Breeze/Dry Gulch Dispersion Model

BRUCE A. KUNKEL

19 November 1984

ATMOSPHERIC SCIENCES DIVISION
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AIR FORCE GEOPHYSICS LABORATORY
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The Ocean Breeze-Dry Gulch (OB/DG) dispersion model is used extensively by the USAF Air Weather Service for predicting the hazard zone resulting from an accidental toxic chemical spill. This model is an empirical and statistical model derived from the Ocean Breeze, Dry Gulch, and Prairie Grass experiments conducted in the late 50's and early 60's. The USAF Scientific Advisory Board recently recommended that the OB/DG model be replaced with a current state-of-the-art dispersion model. This report represents the first step toward evaluating the OB/DG model and finding a suitable replacement. The hazard distances computed from the OB/DG model for different meteorological conditions are compared with the hazard distances calculated with the Shell Oil Co. SPILLS model and a modified version of the model. In the modified Shell model, the discrete Pasquill stability categories are replaced with a continuous stability parameter, and surface roughness is included as a factor in defining the rate of cloud growth. The OB/DG model agrees quite favorably with the modified Shell model except

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at low wind speeds where it predicts considerably lower distances. The Shell model calculates generally larger distances and much greater fluctuations with wind speed, and therefore does not agree as well with the OB/DG model. The similarity in output between the modified Shell model and the OB/DG model lends support to further consideration of this model as a possible replacement to the OB/DG model.

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1. INTRODUCTION

In the late 50's and early 60's the Air Force Cambridge Research Laboratories conducted a series of diffusion experiments in Nebraska,[1, 2, 3] Cape Canaveral, Florida, and Vandenberg AFB, California.[4, 5] These field programs were called Prairie Grass, Ocean Breeze, and Dry Gulch, respectively. The major objective of the Ocean Breeze and Dry Gulch experiments was to acquire sufficient diffusion data to develop an empirical and statistical diffusion model for the missile launches at Cape Canaveral and Vandenberg AFB.

The Ocean Breeze and Dry Gulch tests were conducted primarily during sea breeze conditions. Thus, little data were collected during stable, nighttime conditions. To compensate for this deficiency, the diffusion data from Project Prairie Grass were included in the development of the Ocean Breeze/Dry Gulch (OB/DG) model.

Although the model is designed only for continuous, ground level, point source spills of neutral density gases, it is the only model that the Air Force currently has available for predicting toxic chemical dispersion resulting from accidental spills.

Recently, Ohmstede et al[6] completed a review of the OB/DG equation, comparing its results with three different Gaussian dispersion models—the EPA's Industrial

(Received for publication 13 November 1984)

(Due to the larger number of references cited above, they will not be listed here. See References, page 17.)

Source Complex model, the Army Atmospheric Sciences Laboratory's TOXCOP model, and the Army Dugway Proving Ground's Volume Source Dispersion Model (VSDM). They compared the models for different normalized concentrations (concentration/source strength) and Pasquill stability categories, assuming a given wind speed for each category.

In this report, the OB/DG model is evaluated against the Shell SPILLS model of Fleischer[7] and a modified version of the Shell model. The comparison was done at a given normalized concentration for different wind speeds, cloud, and solar conditions. The Ohmstede study showed that the normalized concentration is not a critical parameter in the comparison of the models, except when the top of the mixing layer acts as a lid and limits the vertical diffusion of the toxic cloud. This comparative study, although similar to the Ohmstede et al study, is a necessary first step toward the development of a replacement model for the OB/DG model. The Shell model was chosen because of its availability and its potential as a possible replacement model. The Shell model has various options that make it suitable for continuous and instantaneous spills, and for buoyant and liquefied gases. The model uses the Pasquill-Gifford diffusion parameters (Reference 8) for the seven stability categories (A-G) and employs Turner's method[9] for defining the category.

As part of the second step toward achieving a replacement model for the OB/DG model, the Shell model was modified by replacing the discrete Pasquill stability categories with a continuous stability parameter devised by Smith[10] and by using Pasquill[11] power-law approximations for different surface roughness lengths for the growth of the vertical and horizontal spread with distance.

A brief description of the models is presented in Section 2, and the model comparisons are presented in Section 3.

2. DISPERSION MODEL REVIEW

2.1 Ocean Breeze and Dry Gulch Model

In 1960, at the request of the Air Force Ballistic Systems Division, the Air Force Cambridge Research Laboratories undertook an extensive program in atmospheric diffusion. The motivation for the program arose from planned launches at Cape Canaveral, Florida and Vandenberg AFB, California, of the Titan II missile whose propellants, if exposed to the atmosphere, emit toxic vapor, causing acute air pollution hazards when substantial quantities are involved.

Field diffusion programs were conducted at Cape Canaveral and Vandenberg AFB during 1961 and 1962. These programs, nicknamed Ocean Breeze and Dry Gulch, respectively, were undertaken to provide data for developing and testing diffusion

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(Due to the number of references cited above, they will not be listed here. See References, page 17.)

prediction equations for operational use at Canaveral and Vandenberg. The diffusion experiments consisted of the release of the tracer, zinc sulfide, over a 30 min period. Membrane filter samplers were placed downwind of the release site along three arcs. The farthest arc was about 5 km from the source. A total of 76 diffusion experiments were conducted at Cape Canaveral and 109 experiments at Vandenberg. The tests were conducted primarily during sea breeze conditions resulting in a strong bias toward unstable conditions. Of the 185 tests, only 24 tests had a positive lapse rate.

Because of the bias in the Ocean Breeze and Dry Gulch experiments, diffusion data from Project Prairie Grass, conducted over flat prairie country near O'Neill, Nebraska, in 1956, was included in the derivation of the diffusion equation. In these experiments, sulfur dioxide gas was released continuously over a 10 min period and sampled along 5 arcs of samplers extending out to 800 m. A total of 68 diffusion experiments were conducted, approximately half of them at night in the presence of temperature inversions.

Of the 253 tests from the three sets of experiments, a total of 220 tests were suitable for use in developing the diffusion prediction equation. Half of these tests were used to derive the diffusion prediction equation and the other half were used to test the equation.

The equation derived from these tests was:

$$C_p/Q = 0.00211X^{-1.96}\ \sigma(\theta)^{-0.506}\ (\Delta T + 10)^{4.33} \tag{1}$$

where

C_p/Q = the normalized peak concentration in sec/m^3,

X = the downwind travel distance in meters,

$\sigma(\theta)$ = the standard deviation of wind direction in degrees of azimuth,

ΔT = the temperature difference in Fahrenheit degrees between 54 ft and 6 ft above the ground ($T_{54} - T_6$).

Based on the independent test data, Eq. (1) predicted 72 percent of the cases within a factor of 2 of the observed values, while 97 percent were within a factor of 4.

They also developed a formula in which ΔT was the only predictor

$$C_p/Q = 0.000175X^{-1.95}(\Delta T + 10)^{4.92}\ . \tag{2}$$

With this formula, 65 percent of the cases were predicted within a factor of 2 of the observed values, while 94 percent were within a factor of 4. It is this latter equation that is used by the Air Weather Service, and is used in this comparative study.

Also derived from the data were probability factors applied to the diffusion equation to obtain certain confidence levels. This allows one to determine the distance downwind in which the peak concentration will not exceed a prescribed value a given percentage (for example, 90 percent) of the time. The procedure for using this model is described in a report by Kahler et al.[12] The model assumes there is no capping inversion.

2.2 Shell SPILLS Model

The SPILLS model is an unsteady-state Gaussian puff model. It estimates the concentration of vapors resulting from a spill as a function of time and distance downwind of the spill. It treats three different spill scenarios: (1) continuous liquid or gas spills, such as leaks from tank cars, tanks, or pipelines; (2) instantaneously-formed pools of liquid or liquefied gases; and (3) stacks, where the emission rate is assumed to be known. The output from the model can be presented in three different forms: (1) maximum concentrations at a given elevation and elapsed time since the spill, (2) concentration at a given time and position in space, and (3) constant concentration contour plots for a given elevation and elapsed time.

The model contains the necessary thermophysical properties of 36 potentially hazardous materials. The data base can be easily expanded to include the chemical properties of other substances.

The model uses the Pasquill-Gifford horizontal and vertical diffusion parameters (σ_y, σ_z) for the seven categories of stability (A-G) and employs Turner's method[9] for defining the category. Diffusion experiments have suggested that horizontal diffusion is actually greater during the very stable category G condition than under conditions associated with category F because the plume often meanders during G conditions. The model asumes that under these conditions both diffusion parameters are similar to those for the neutral D conditions.

2.3 Modified Shell SPILLS Model

In this study, two major changes were made to the SPILLS model; (1) the discrete stability categories were changed to a continuous stability parameter and (2) the Pasquill-Gifford vertical and horizontal diffusion parameters (σ_z, σ_y) were computed from power-law approximations and made dependent on surface roughness.

12. Kahler, J.P., Curry, R.G., and Kandler, R.A. (1980) Calculating Toxic Corridors, AWS/TR-80/003, AD A101267.

A model developed by Myirski[13] and based on the work of Smith[10] was used to determine the continuous Pasquill stability parameter, which varies from 0 for the most unstable case to 6.0 for the most stable situation. Smith has utilized numerical solutions of the diffusion equation up to 100 km downwind, and by a process of interpolation has constructed a nomogram giving the stability parameter as a function of wind speed and incoming solar radiation during the daytime, and wind speed and cloud amount at night. The nomogram is reproduced in Figure 1.

Since the incoming solar radiation is not normally measured, an additional routine was added to Myirski's model to calculate the radiation based on the sun's zenith distance and, for overcast conditions, the type of clouds. The direct solar radiation I that falls on a unit horizontal area at the earth's surface in time dt is

$$\frac{dI}{dt} = \frac{J_o}{r^2} a^{\sec z} \cos z \qquad (3)$$

where a is the transmission coefficient of the atmosphere, r is the radius vector of the earth, J_o is the solar constant, and z is the sun's zenith distance. A transmission coefficient of 0.7 was used in the model. The amount of solar radiation reaching the ground through an overcast depends on the optical air mass and the type of cloud cover. Table 152 in the Smithsonian Meteorological Tables[14] gives the ratio of insolation with overcast sky to insolation with cloudless sky for different cloud types and optical air masses. The ratio used in the model corresponds to an optical air mass of 2.0, or a zenith distance of 60°. When the incoming solar radiation has been determined, Myirski's model is then used to determine the stability parameter. One slight change was made in his formula for the stability parameter for nighttime conditions with winds between 2 and 5 m/sec. This change allows a slightly more accurate fit to the Smith curves during these conditions.

Figure 2 shows the stability categories for different solar angles, cloud amounts, and wind speeds for both daytime and nighttime using Myriski's model and Turner's method[9] of defining the stability categories. With Myriski's model, the dividing lines between categories are more diffuse and the transition from one category to the other is gradual, rather than an abrupt change. Under certain conditions, Turner's method can result in the skipping of a category when there is a slight change in wind speed and cloudiness or solar angle, thus resulting in large changes in the hazard distance.

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13. Myirski, M.M. (1983) A Computer Program for Estimating the Vertical Diffusion Parameters of a Chemical Cloud Released Near the Surface, U.S. Army Chemical System s Laboratory, ARCSL-TR-83009.

14. List, R.J., Ed., (1956) Smithsonian Meteorological Tables, Smithsonian Miscellaneous Collections, Vol. 114.

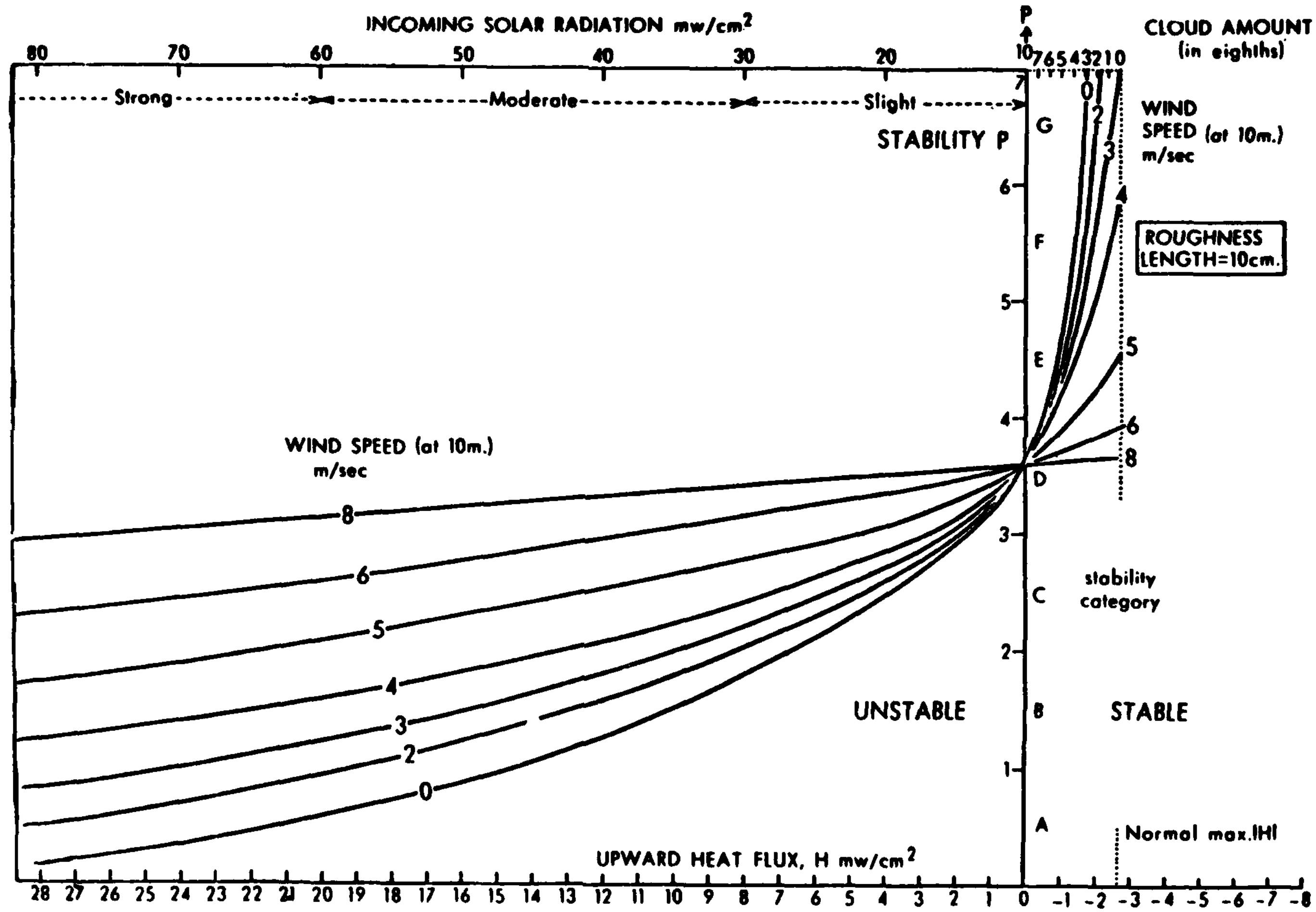

Figure 1. Stability Parameter as a Function of Windspeed, Insolation, and Cloud Cover (from Reference 10)

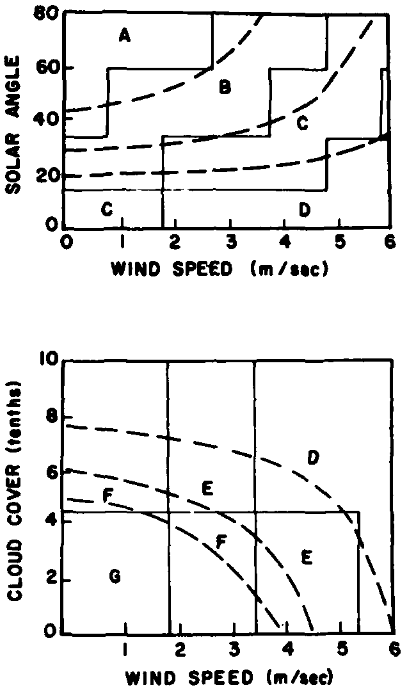

Figure 2. The Stability Categories as a Function of Solar Angle, Cloud Amount, and Wind Speed for Both Daytime and Nighttime Using Myriski's Model and Turner's Method of Defining the Stability Categories

Having obtained the stability parameter we then used a linear interpolation scheme to obtain the horizontal and vertical diffusion parameters (σ_y, σ_z) from Pasquill power-law approximations.

The power law expressions are:

$$\sigma_y = ax^b \tag{4}$$

$$\sigma_z = cx^d \tag{5}$$

where

x = downwind distance from the source

a, b, c, d = coefficients considered to be roughness and stability dependent. The values of c and d for the vertical diffusion parameter are reproduced in Table 1 from Pasquill.[11] These values apply when σ_z and x are in km.

Table 1. Coefficients for Power-law Approximation for the Growth of Vertical Spread With Distance, for a Source at Ground Level (Pasquill[11])

Stability Category	c			d		
	z_o			z_o		
	1 cm	10 cm	100 cm	1 cm	10 cm	100 cm
A	0.102	0.140	0.190	0.94	0.90	0.83
B	0.062	0.080	0.110	0.89	0.85	0.77
C	0.043	0.056	0.077	0.85	0.80	0.72
D	0.029	0.038	0.050	0.81	0.76	0.68
E	0.017	0.023	0.031	0.78	0.73	0.65
F	0.009	0.012	0.017	0.72	0.67	0.58

The σ_z values computed by this technique, assuming z_o = 10 cm, are similar to those determined from the Pasquill-Gifford curves,[8] except for the more unstable conditions where the sharp increase in σ_z in category A no longer exists.

The Pasquill-Gifford curves used in the Shell model for the horizontal diffusion (σ_y) were also used in the modified Shell model. However, the formulation used in the Shell model was replaced with the power-law expression. The horizontal diffusion was also assumed dependent on the roughness length, z_o, by the following expression: $\sigma_y(z_o) = \sigma_y(0.1\ \mathrm{m})\ (z_o/0.1\ \mathrm{m})^{0.2}$. The σ_y for z_o = 0.1 m can be determined by using the coefficient shown in Table 2. These coefficients apply when σ_y and x are in meters.

Table 2. Coefficients for Power-law Approximation for the Growth of Horizontal Spread With Distance, for a Source at Ground Level

Coefficient	Stability Category					
	A	B	C	D	E	F
a	0.40	0.32	0.22	0.142	0.102	0.076
b	0.9	0.9	0.9	0.9	0.9	0.9

These formulas do not include stability category G and, therefore, when the stability parameter falls within category G(> 6.0) the stability parameter is set at 6.0, or at the stable end of the F category. Therefore, during very stable conditions the two Gaussian models are not directly comparable since the Shell model

assumes meandering of the plume (thus larger diffusion coefficients) and the modified Shell model does not.

For the modified Shell model, a linear regression line for c and d for each of the three z_o was derived. Then using the regression equation, the appropriate c and d values for the given stability were determined and the σ_z computed using the power law equation. If the actual z_o was between 1 and 10 cm or 10 and 100 cm, the σ_z was determined by linearly interpolating between the σ_zs for z_o of 1 and 10 cm or 10 and 100 cm. For the horizontal diffusion, the "a" coefficient can be related to the stability parameter (S) by a parabolic regression line:

$$a = 0.479 - 0.1232\,S + 0.00904\,S^2 . \tag{6}$$

The σ_y can then be computed through the power law formula [Eq. (4)].

3. MODEL COMPARISON

In the comparison of the three models, it is assumed that the spill is a ground level, continuous spill and has reached steady state. In the revised Shell model, a roughness length of 10 cm was used. This is a reasonable roughness length for the OB/DG experiments. In the OB/DG model a probability factor of 1 was used meaning that 50 percent of the time the actual hazard distance would be greater than that predicted, and 50 percent of the time it would be less than that predicted. For times when the vertical temperature gradient (ΔT) is not available, the AWS has devised a set of tables[12] that relate ΔT (to the nearest Fahrenheit degree) to the wind and sky conditions for daytime and nighttime. These tables are used in this study and are presented in Table 3. Since the OB/DG model does not consider mixing depth, the mixing depth was set at an arbitrarily high value in the Gaussian models so it would not be a factor.

Figures 3, 4, and 5 illustrate how the results of the three models (OB/DG, Shell, modified Shell) compare with each other under varying meteorological conditions. The distance in the figures represents the distance downwind from the spill that you would expect 30 mg/cm^3 (10 PPM) concentration resulting from a spill of benzene with a source strength of 1 kg/sec. Although Figures 3, 4, and 5 are for a particular source strength and concentration, (that is, normalized concentration, C_p/Q) the relative results are similar for other normalized concentrations. The exception is under very stable conditions (clear nights, light winds) where the smaller the normalized concentration, the greater the ratio of the hazard distance computed from the Gaussian models to that computed from the OB/DG model. In other words, the larger the spill and/or the smaller the concentration of interest, the greater will be the difference in distance computed by the two models; the OB/DG model will compute smaller distances than the Gaussian models.

Table 3. Estimation of Temperature Differences Between 6 and 54 ft (in Fahrenheit degrees) for Different Wind Speeds, Solar Angles, and Cloud Amounts (from Reference 12)

	Day				Night					
	Incoming Solar Radiation (Solar Elevation Angle)				Clear		Cloud Cover 1/8-3/8		Cloud Cover 4/8-8/8	
Surface Wind Speed (kt)	Strong (≧ 60)	Moderate (36-60°)	Weak (16-35°)	Sunrise/Sunset (≦ 15°)	Snow	No Snow	Snow	No Snow	Snow	No Snow
	Clear Sky or Scattered Clouds									
≦ 3	-2	-1	-1	0	6	5	5	4	4	3
4-6	-3	-2	-2	0	6	5	5	4	4	3
7-10	-3	-2	-1	0	5	4	4	3	3	2
≧ 11	-2	-1	-1	0	5	4	4	3	2	1

Broken Clouds — Abv 7000 ft - A (>); Equal to & Blo 7000 ft - B (≦)

Surface Wind Speed (kt)	Strong A	Strong B	Moderate A	Moderate B	Weak A	Weak B	Sunrise/Sunset A	Sunrise/Sunset B
≦ 3	-1	-1	-1	-1	-1	0	0	0
4-6	-2	-2	-2	-2	-2	0	0	0
7-10	-2	-1	-1	-1	-1	0	0	0
≧ 11	-1	-1	-1	-1	-1	0	0	0

Overcast Clouds

Surface Wind Speed (kt)	Strong A	Strong B	Moderate A	Moderate B	Weak A	Weak B	Sunrise/Sunset A	Sunrise/Sunset B
≦ 3	-1	0	-1	0	-1	0	0	0
4-6	-2	0	-2	0	-2	0	0	0
7-10	-1	0	-1	0	-1	0	0	0
≧ 11	-1	0	-1	0	-1	0	0	0

Note 1. Use sunrise/sunset category during the period from one hour before to one hour after sunrise/sunset.

Note 2. In rough terrain add (-1) to the number determined.

Note 3. If the toxic corridor is in a forest, use the next lower wind speed category than normal (unless the wind measurement is from within the forest canopy) and add (-1) to the resulting delta-T value. Do not use a delta-T more negative than (-4).

Note 4. Major Robert G. Curry developed this table while assigned to 3WW/DN. It originally appeared in 3WWP 105-13 and more recently in AWSP 105-57.

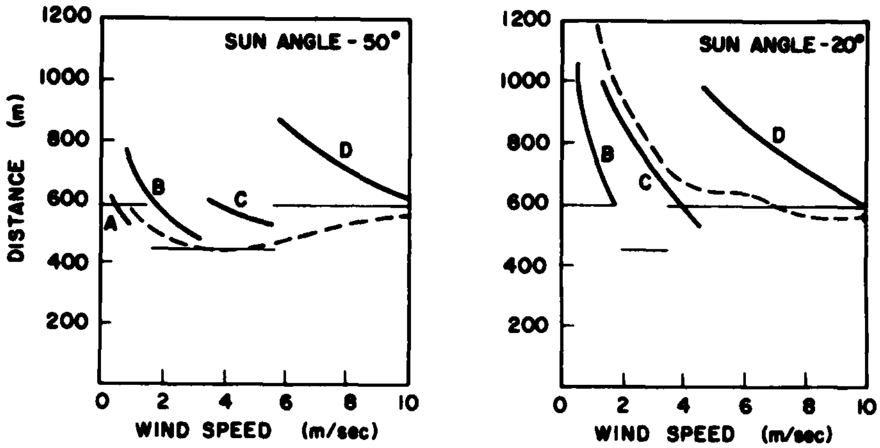

Figure 3. Model Estimates of the Hazard Distance for Benzene as a Function of Wind Speed for a High (50°) and Low (20°) Sun Elevation Angle. The source strength is 1 kg/sec and the concentration of interest is 30 mg/m^3. The light solid line represents the OB/DG model, the heavy solid line represents the Shell Model, and the dashed line represents the Modified Shell Model. The letters represent the Pasquill stability category used in the Shell Model

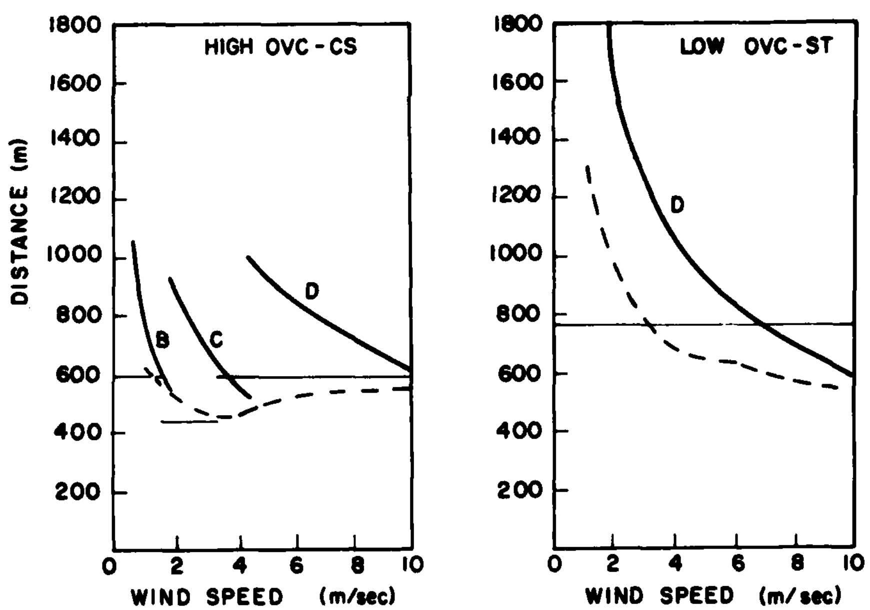

Figure 4. Model Estimates of the Hazard Distance for Benzene as a Function of Wind Speed, for High and Low Overcast With a Sun Angle of 50°

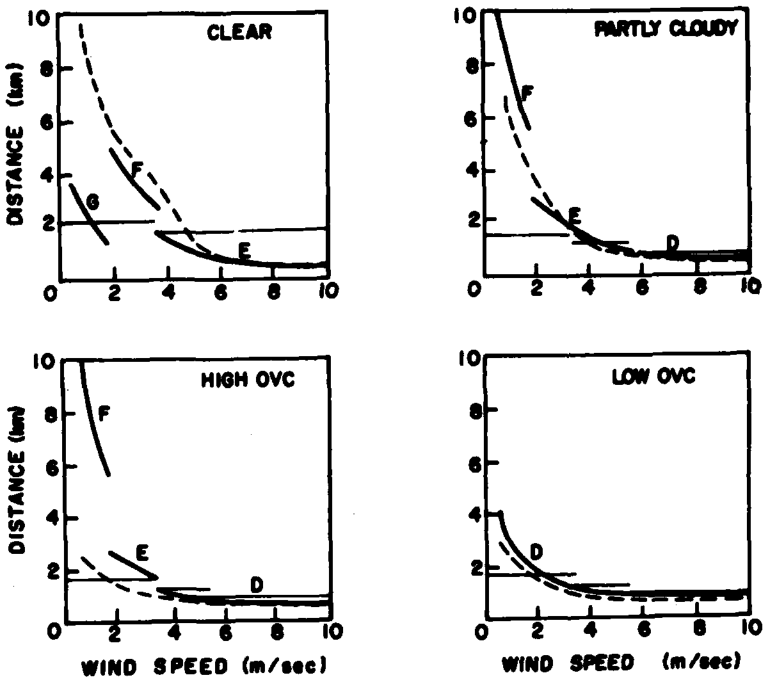

Figure 5. Model Estimates of the Hazard Distance for Benzene as a Function of Wind Speed, for Four Different Nighttime Conditions - Clear, Partly Cloudly, High Overcast, and Low Overcast

The discontinuities in the distances caused by using discrete stability categories are very much in evidence in all the figures. Increases of approximately 70 percent in hazard distances are noted in the Shell model when shifting to the next more stable category. With the OB/DG model, the discontinuities are less severe, averaging around a 30 percent increase in distance. Of course, if actual ΔTs can be used, there would be no discontinuities. The modified Shell model has no discontinuities because of the use of the continuous Pasquill stability parameter.

In the Gaussian models, increasing wind speed decreases the hazard distance as apparent in the Shell model where the stability is held constant. In the modified Shell model, during the daytime, the decreasing hazard distance with increasing wind speed is counteracted by an increasing stability with wind speed which increases the hazard distance. As a result, the hazard distance may either increase or decrease with wind speed depending on how rapidly the stability changes. Generally, at high sun angles, the hazard distance is relatively constant with wind speed with the shortest distance occurring around a wind speed of 4 m/sec. At lower sun angles, the hazard distance changes rapidly at wind speeds below about 4 m/sec and levels off at wind speeds greater than 4 m/sec.

In Figure 3, the Shell model, for many wind speeds, shows no change in the hazard distance with a change of 30° sun angle because the stability category remains the same. The modified version of the Shell model shows an increase in hazard distance at all wind speeds as the sun goes from 50° to 20° because of the increasing stability. In some wind situations the hazard distance increases by a factor of 2 to 3, as the sun angle shifts from 50° to 20°.

During high sun angle and clear conditions (Figure 3), the OB/DG model produces shorter distances than the Shell model for all wind speeds. On the other hand, the OB/DG model agrees quite well with the modified Shell model. For low sun angle and clear conditions, the OB/DG model produces, for most wind speeds, shorter distances than the Shell model. Comparing the OB/DG model with the modified Shell model shows an excellent agreement for wind speeds greater than 4 m/sec. However, for lighter winds and more unstable conditions, the OB/DG model produces significantly shorter distances than the modified Shell model.

Under high sun angle and high overcast conditions, the OB/DG model agrees quite well with the modified Shell model (Figure 4). However, under low overcast conditions, the OB/DG model, which assumes a constant neutral stability, produces greater distances for stronger winds (> 3 m/sec), and shorter distances for light winds than the modified Shell model. The Shell model generally produces larger distances than the other two models for both high and low overcast, except for low overcast and high wind speed conditions. For low overcast and light wind conditions, the Shell model produces distances more than double those of the OB/DG model. In the Shell model, high overcast is defined as any cloud layer above 4900 m, and a low overcast is any cloud layer below 2100 m. The hazard distances for the modified Shell model are for a high overcast of cirrostratus with a solar insolation rate of 50 mw/cm^2 and a low overcast of stratus with a solar insolation rate of 16 mw/cm^2.

At nighttime, the hazard distance is a function of cloud amount and wind speed. The Shell model discriminates between medium or high clouds (> 2100 m) and low clouds (< 2100 m). The Shell model also includes a Category G (very stable) which produces shorter distances than Category F because of plume meandering which occurs under very stable and light wind conditions. As seen in Figure 5, the biggest discrepancy between the OB/DG and the Gaussian models occurs during light wind and clear or partly cloudy conditions. The OB/DG model calculates much smaller distances than the Gaussian models. This fact was also pointed out by Ohmstede et al.[6] This discrepancy is not surprising considering that most of the Ocean Breeze and Dry Gulch experiments were conducted under unstable atmospheric conditions. Another discrepancy occurs during windy clear nights when the OB/DG model predicts distances 3 to 4 times greater than either Gaussian model. It would appear that the +4°F (2.5°C) temperature difference used in the OB/DG model under these

conditions is excessive. A ΔT of $+1°F$ at the higher wind speeds would result in closer agreement with the Gaussian models.

The modified Shell model agrees quite well with the shell model under clear, partly cloudy, and low overcast nighttime conditions. The exception is during stability G conditions. The major difference occurs during high overcast, light wind conditions when the Shell model produces greater distances than either the modified Shell or OB/DG model. The modified Shell model does not differentiate between high and low overcast during nighttime conditions.

The comparison was made with the other chemicals in the Shell model, and in all cases the distance ratios were the same. In making the comparison, however, care must be taken to use sufficiently small source strengths so that the pool width, computed by both Shell models, does not become excessively large. Otherwise, the Shell models treat the spill as an area spill and can no longer be correctly compared with the OB/DG model which assumes a point source spill. This is especially critical for less volatile chemicals such as ethylene glycol and 2-ethyl hexanol. Spreading the chemical over a larger area to obtain the desired source strength results in lower concentrations at a given downwind distance, and thus lower ratios.

4. CONCLUSIONS

Despite the simplicity of the OB/DG model, it compares quite favorably with the modified Shell model, except in light wind situations when it predicts much lower hazard distances. Agreement is not as good with the Shell model because of the large fluctuations in hazard distance computed with the Shell model when shifting from one stability category to the other. When averaging all the data from the cases that make up Figures 3, 4, and 5, the hazard distances computed from the Shell model average 27 percent greater than those computed from the OB/DG model. The modified Shell model distances averaged 15 percent greater than from the OB/DG model. In other words, the OB/DG model is not as conservative as the Gaussian models. The AWS normally multiplies the hazard distance by a probability factor of 1.63 which defines the distance that the specified concentration will not exceed 90 percent of the time. This 63 percent increase would result in hazard distances greater, on the average, than either Gaussian model.

During daylight hours, the major discrepancy occurs during light winds (< 3 m/sec) and low solar insolation (either due to low sun angle or thick overcast). During these situations, the Gaussian models can produce distances twice as great as the OB/DG model.

At nighttime, the major discrepancies occur during light winds (< 2 m/sec) and clear, partly cloudy, or high overcast conditions, or in terms of stability category,

during Category F conditions. The Gaussian models can produce distances 5 times greater than the OB/DG model. The use of the G stability category in the Shell model actually brings the hazard distance more in line with the OB/DG model. The other major discrepancy occurs during windy (> 5 m/sec) clear nights. The OB/DG model, using a ΔT of +2.5°C (+4°F) computes hazard distance 2 to 4 times greater than the Gaussian models. It would appear that the use of a smaller ΔT would be more appropriate.

The major disadvantage of the OB/DG model is in its limited application. It is limited to ground level, point source, continuous spills of neutral density gases, or if used in combination with a evaporative source strength model, instantaneous liquid spills. It is not suitable for buoyant, heavy, or liquefied gases, and does not take into account the height of the inversion layer. The presence of such an inversion could greatly increase the hazard distance of a large spill. The model is also designed specifically for spills over surfaces with a roughness length of about 10 cm.

5. RECOMMENDATIONS

The similarity in output between the modified Shell model and the OB/DG model lends support to considering the modified Shell model as a candidate replacement to the OB/DG model. It computes similar hazard distances under those meteorological conditions in which there is a fair degree of confidence in the OB/DG model, and is suitable for a much wider range of spill scenarios.

Work on the model will continue in order to make it more precise and more versatile. Some of the improvements that are planned include: (1) determining mean concentrations for different exposure times, (2) an option to use the fluctuation in horizontal and vertical wind directions for computing the dispersion parameters (σ_y, σ_z), (3) a variable wind direction and speed with time and space, with the intent of eventually combining the dispersion model with a surface wind flow model for use in complex terrain situations, and (4) the addition of the heavy gas effect. Efforts will also be made to improve the computational efficiency of the model and its choice of output options. The model will also be expanded to include those chemicals that are of primary concern to the Air Force.

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